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FUTURE DIRECTIONS OF C3 RESEARCH AT DARPA

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ABSTRACT

Research into C3 related problems is a major effort of the Information Science and Technology Office of the Defense Advanced Research Projects Agency. The major thrusts of projects is in the area of future, high-risk efforts, often resulting in the development of a conceptual model or prototype. Some of these prototypes are then further developed to provide an infrastructure for future research. The programs can be divided into two groups: base technology research programs and testbed programs. The testbeds provide a focus for the technology programs.

1. OVERVIEW

The C3 Technology Division of the Information Science and Technology Office (ISTO) of the Defense Advanced Research Projects Agency (DARPA) is responsible for development of advanced technologies that support reliable and efficient advanced C3 architectures and operations. As mobility and distribution are key in implementing such advanced C3 structures and play a fundamental role in the way the military services anticipate operating in the future, emphasis is placed on those technologies that will support mobile distributed operation.

Previous developments in computer communication networking carried out by DARPA, in particular the development of the concept of packet switching, have already proved themselves to be useful and important. Through both transfer of the technology directly (e.g., the Defense Data Network (DDN)) and through use of the technology in joint testbeds with the military services (e.g., Ft. Bragg Testbed and Strategic C3 Experiment), the use of packet-switched computer communications to accomplish reliable and flexible data communications with associated C2 services (such as electronic mail) has been shown to be important and useful to the military. However, the current technology available will not support the anticipated requirements of the future. In particular, concepts being developed by the military such as the high-mobility/distributed operation of the Army 21 concepts and doctrine require technologies in both computer processing and computer communications that will allow robust and reliable operation in a mobile and distributed environment. In addition, recent emphasis within the DoD on the use of commercial equipment along with likely NATO decisions to employ commercial standards require the development of mechanisms to interoperate among a number of different systems, including advanced systems as described here, existing military systems, and emerging commercial standards.

An additional aspect of developing advanced C3 systems is the development of architectures, concepts, and methods of operation to achieve the goals of survivability and effectiveness. While the building blocks of the advanced distributed communications and computer processing technologies are necessary, the technologies alone are not sufficient to achieve those goals. Furthermore, understanding of the most effective ways to operate in a distributed environment is a technology issue as well as an operational issue.

Thus, the C3 Technology Program has four main thrusts. First is the development of advanced distributed computer communications technologies to support mobile and distributed C2 operations. Second is the development of advanced distributed computer processing techniques. Third is the development of mechanisms to allow interoperability between systems developed with different requirements locally but having a broad common objective. Finally is the development of C3 architectures that apply the above technologies to achieve the required level of survivability and effectiveness anticipated to meet future DoD requirements. Each of these main thrusts is met by developing

programs that can be divided into two main categories: base technology research programs and testbed programs.

In the next section of this paper, each of the programs required to achieve the above objectives is described. Note that some of these programs already exist while other programs are proposed new directions. Many of the programs described overlap into more than one of the four thrust areas described above.

2. BASE TECHNOLOGY RESEARCH PROGRAMS

2.1. ADVANCED NETWORKING TECHNOLOGIES

The programs in this area are aimed at developing advanced communication network architectures that support reliable and robust communications. While chiefly aimed at computer communications, many of the techniques developed also have application in the voice area.

2.1.1. ADAPTIVE NETWORKS

This is an existing basic research program aimed at developing the underlying theory to support advanced communication network techniques. The major thrusts in this area are the development of algorithms that will permit dynamic distributed sharing of communication resources, the distributed and automatic management of highly complex distributed networks, and the development of an adequate theoretical base for determining the performance (both expected and actual) of different network architectures and algorithms. Like all basic research, this area will evolve as new theoretical ideas emerge.

2.1.2. SURVIVABLE RADIO NETWORKS

The Survivable Radio Network (SURAN) program is an existing program aimed at developing the algorithms and architectures that will permit large computer communication networks to be operated in the presence of a sophisticated threat environment. While based on broadcast radio technology and the previously developed packet radio techniques, the understanding of protocol vulnerabilities and how to counter them will have an impact on many networks.

Development of SURAN requires the development of a low-cost, high-performance packet radio (LPR) to permit experimentation with the SURAN concepts; the development of the algorithms and software to run in the radios that effect the network management and control, which is the heart of the effort; and the definition of advanced threats that can be mounted against such networks by enemies having similar levels of distributed C3 technology. The current SURAN effort is attacking all of these areas, and no modification of the program goals is required.

2.1.3. NETWORK SECURITY

The network security program is an existing program aimed at developing the advanced techniques required to provide communications security (protection of the information) and access control for packet-switched networks. This program has developed an end-to-end security system (the Internet Private Line Interface (IPLI)) jointly with the Defense Communications Agency (DCA) and the National Security Agency (NSA) and is preparing to deploy it in the Army/DARPA Distributed Communications and Processing Experiment (ADDCOMPE) and Strategic C3 Experiment testbeds. It has also developed privacy and access control mechanisms for use on the Internet. While some further efforts are anticipated in this area to ensure that the proper facilities are available to use on the internet system, it is expected that the need for an explicit effort in the area of end-to-end security mechanisms will diminish, as NSA is developing such mechanisms for DDN and related networks. However, there is a need for developing appropriate security mechanisms for distributed C3 systems beyond just end-to-end encryption and access control.

2.1.4. WIDEBAND SATELLITE NETWORK

The Wideband Satellite Network (WBnet) program is an existing program to develop and demonstrate a system that can provide wideband (3 Mbit/s) flexible communications through the sharing of a single satellite channel by multiple ground stations. This system has a number of advantages over conventional satellite systems in that it allows flexible and dynamic sharing of the satellite capacity. It also has the capability of supporting digitized voice and other media (such as video) because of its substantial bandwidth.

The WBnet has almost achieved its goal of demonstrating the technology, and will do so by the end of this year. At that point, the remaining task will be to integrate the network into the rest of the internet system in a way that will permit intelligent use of the enhanced services available because of the wide bandwidth that is available. This task will be accomplished under the Internet Program.

2.1.5. MULTIMEDIA NETWORKS

This is a new effort aimed at developing network management and control strategies for networks, particularly radio networks, where the link communications are provided through the use of a number of different media. One component of achieving communications survivability is the use of diverse communications media, such as VHF, troposcatter, millimeter wave, satellite links, etc. Conventional communications approaches have been explored to achieve this diversity through the use of multiple links between the end nodes. In the internet context, a different approach can be used if individual networks are designed, one per media, and then internetted. However, neither of these approaches can attain the robustness and survivability that can be achieved through using a richly interconnected set of links, each one having multiple media, and

the overall network management using the links and media as required to achieve the best performance given the available media, links and nodes.

2.2. DISTRIBUTED PROCESSING TECHNIQUES AND ARCHITECTURES

Achieving distribution and mobility of command and control requires more than just the availability of appropriate communications. It is also necessary to be able to distribute the computer resources (both hardware and algorithms) in a way that is survivable (i.e., can tolerate the loss of a sizable number of computing nodes). The purposes of this area are to develop the computer processing technology that will allow such distribution to take place and to develop the tools for understanding and building distributed C3 architectures.

2.2.1. DISTRIBUTED SOFTWARE

This is an existing program aimed at the development of distributed operating systems and distributed utility programs. Important areas being addressed in this program include the use of networked personal computers to support a user community, identification of the linguistic features needed for effective development of distributed applications, creation of a distributed computing environment by enhancing a widely used single-machine operating system, and investigation of the distributed system architectural features needed to increase the survivability of a secure information processing resource. Distributed systems implemented in this program will be applied in the joint military testbed efforts described below.

2.2.2. DISTRIBUTED SYSTEM SECURITY

The communication security aspects of a distributed C3 system have been successfully attacked in the Network Security program up until now, and further work is being done by NSA (e.g., Blacker). However, the proper way to include security considerations in a distributed C3 system is not well understood, and must be considered as an integral part of any distributed system development for it to be relevant to the military. This program is a new effort aimed at developing the technologies and architectures to appropriately include security in distributed software systems. An example of the issues to be considered is what modules should have access to which data bases in order to provide the required survivability and robustness and yet have adequate control over the data and the system itself to insure no compromise of either the data or system operation.

2.2.3. DISTRIBUTED C3 SYSTEMS ARCHITECTURE

This is a new program aimed at developing and demonstrating the underlying theory for distributed C3 systems, especially with respect to features that support evolution. C3 systems provide services to C3 users, i.e., the battlefield commanders and support personnel who need specific information, analysis and decision support processing, and

command dissemination and effectuation capabilities. These needs change continuously as the operating environment, threat characteristics, tactical doctrine, user experience, and applicable technology all evolve. This program will develop and provide practical demonstrations of the theory of evolutionary C3 systems architectures based on modeling C3 systems as complex collections of interacting service providers and service users. The program will use modern systems of standards being developed within the DoD Internet and commercial ISO communities, and will seek out cooperative joint application opportunities with military research and development organizations.

2.3. INTEROPERABILITY TECHNOLOGY

To meet the requirements of individual commanders in the environments that their units will likely operate requires the development of systems tailored to those requirements and environments. For example, the communication system required to support a widely dispersed highly mobile Army operation will likely have considerably different characteristics than that designed to support strategic long-haul communication needs. At another level, systems designed to meet commercial requirements with their emphasis on cost-effectiveness and accounting are unlikely to meet the military requirements of robustness, survivability and security. Yet, there is a need for all of these systems to be able to interoperate in a number of ways. First, there is a need to be able to pass information among the various military systems and between U.S. and NATO systems. In addition, there is a desire to be able to use available commercial systems where applicable, both as primary systems and as backup communication systems. The programs in this area are aimed at developing the technologies to achieve this interoperability.

2.3.1. INTERNET TECHNOLOGY

This is an existing program currently aimed at developing and demonstrating the means for interconnecting computer communication networks in a robust way by using packet-switching gateways. An important aspect of the program has been the development of standard protocols for exchange of information between dissimilar systems. A number of these protocols have been adopted as DoD standards and mandated for use in all packet-switched networks where interoperability is a concern.

The current Internet system allows for the interconnection of a sizable number of networks. Further efforts in this program are aimed at developing algorithms for interconnecting large numbers of networks in a survivable and robust manner (note relationship to SURAN program above), developing mechanisms for autonomous systems of networks and gateways to be interconnected, enhancing the types of service available through inclusion of additional networks such as the Wideband Satellite Network, developing mechanisms to permit interoperability with commercial and NATO networks,

and developing new distributed applications making use of the full capabilities of internet communications.

2.3.2. INTERNATIONAL COOPERATION EFFORT

To work towards an international (NATO) interoperable C3 capability, this existing program was established involving researchers in a number of NATO countries. The goals of this program are to develop and demonstrate mechanisms to achieve command and control interoperability based on the availability of an interoperable Internet communication system.

Currently, the funded efforts within the program are aimed at maintaining the infrastructure for communications, in particular the Atlantic Packet Satellite Network. Joint experiments are carried out and funded by the participating activities, usually one of the ongoing DARPA programs and one or more of the NATO activities. For example, Internet experimentation has been carried out jointly by researchers in the Internet program and researchers in each of the participating NATO countries. However, a plan is being drafted that is aimed at initiating a number of joint projects to develop and demonstrate interoperable capabilities. As this plan matures and agreement is achieved, funding will be required for DARPA participation in those areas where a program does not already exist.

3. TESTBED PROGRAMS

The base technology research programs described above provide the mechanisms and technologies to support distributed command and control. However, an additional step is required, i.e., the development of new ways of doing command and control so as to achieve the desired objective of a highly robust and survivable system. The programs described in this area are aimed at developing those mechanisms by placing emerging technologies into realistic user environments to evaluate their applicability to future C3 requirements. Testbed programs are conducted jointly with the military to develop, test, and demonstrate new C3 techniques based on advanced C3 technologies developed both by DARPA and the military.

3.1. COMMUNICATION TESTBEDS

This area addresses the need for providing adequate communication resources to carry out a research program in distributed C3. These requirements are of two distinct forms. The first is to provide the appropriate communications media in support of the research activities. These can be as elementary as electronic mail and as sophisticated as provision of a robust and diverse communication system to develop such C2 services as multimedia conferencing. The second is the provision of the required communication services to support demonstration of the advanced C3 capabilities developed under the overall C3 area.

The success of the efforts in packet-switched communications research is in large part due to the use made by the researchers of the communication systems they have developed. For that reason and a number of practical cost-related reasons, we have chosen to maintain a number of networks in support of our research activities. These include the Arpanet, the Atlantic Satellite Network, and the Internet gateway system. In addition, as the Wideband Network becomes stable, it will be converted into this category in support of enhanced C3 capabilities requiring wideband services.

3.2. DISTRIBUTED SENSOR NETWORKS

The Distributed Sensor Networks (DSN) program is an existing effort aimed at developing and demonstrating a system that can achieve a common goal in a highly survivable way through the use of distributed autonomous but cooperating processes. The particular application being investigated is the tracking of low-flying aircraft through the use of distributed acoustic arrays with associated processing and communications capability. However, the technology will be applicable to a number of other systems.

3.3. STRATEGIC C3 EXPERIMENT

This is an existing program, being conducted jointly with DCA, the Strategic Air Command (SAC), and the Rome Air Development Center (RADC), aimed at exploring the use of advanced communication and processing technologies to support the reconstitution of C3 in a post-nuclear strike environment. The main thrusts of this program are airborne packet radio, distributed data bases, and communications reconstitution applied to the bomber recovery scenario. The program culminates in a total systems demonstration in 1986.

3.4. SURVIVABLE ADAPTIVE PLANNING EXPERIMENT

The Survivable Adaptive Planning Experiment (SAPE) is a concept for a survivable adaptive network whose purpose is to demonstrate critical elements of a survivable strategic C3I environment and a rapid adaptive strategic mission planning capability operating in that environment. The main thrusts of this program are enduring connectivity, adaptive replanning, and demonstration of a reconfigurable high-bandwidth communication system that supports enduring connectivity and can also provide a baseline for the Multiple Satellite System described earlier. Initial planning aimed at establishing a joint program to perform this effort is under way with RADC, SAC, and the Joint Strategic Target Planning Staff (JSTPS).

The efforts to be pursued under SAPE will build upon and extend the capabilities initiated under the Strategic C3 Experiment. The testbed configuration will be extended in both the communications and data processing areas. Wideband satellite communications links will be added to extend the geographic range of the C3I linkage. VLF, HF, and satellite communications links will be added to integrate the emergency action message function and augment the available connectivity. Advanced adaptive networking technology being

developed under the Multiple Satellite System (MSS) program will be used to provide repeater nodes carried on airborne platforms. This will provide the survivable high-bandwidth data communication capability essential to a distributed rapid adaptive planning system. Distributed processing technologies will be developed and demonstrated, which will permit the realization of distributed computing architectures needed for survivable planning elements. Recent advances in computer graphics and knowledge-based and natural language systems will be applied to design and will help build automated software tools to facilitate adaptive planning. These tools will be integrated with current and emerging artificial intelligence (AI) planning research results to implement a prototype rapid adaptive planning system.

3.6. BATTLEFIELD DATA DECENTRALIZATION

The Army/DARPA Distributed Communications and Processing Experiment (ADDCOMPE) is an existing joint effort to explore the use of distributed communications and processing technologies to support survivable C3. This effort is using advanced packet-switched internet communications technology to support the exploration of distributed command and control concepts. The Battlefield Data Decentralization program is aimed at developing and demonstrating advanced distributed C3 applications in support of ADDCOMPE.

3.7. MULTIPLE SATELLITE SYSTEM

The Multiple Satellite System (MSS) program is an existing effort to develop a highly survivable satellite network through the use of proliferated low-cost satellites. The concept is based on the use of proliferation along with cross-linking of low-orbiting satellites and sophisticated signal processing techniques to achieve a high degree of survivability at an achievable cost.

Because deployment of an MSS would be expensive, the current plan is to develop the required MSS payload (i.e., a low-cost satellite with advanced communication processing equipment) but test the system through the use of long-endurance RPVs. The detailed planning for this development is currently under way and is being coordinated with planning for the development and demonstration of a system to provide enduring strategic connectivity.

3.8. NATO DISTRIBUTED WARFARE SIMULATION PROGRAM

The Defense Advanced Research Projects Agency (DARPA), Defense Communications Agency (DCA), Rome Air Development Center (RADC), and the SHAPE Technical Center (STC) will conduct a joint program of research, development, demonstration, and evaluation of a means for improved NATO warfare capabilities through the development and use of an advanced distributed warfare simulation capability. Because of recent advances in computer science and telecommunications, an exceptional opportunity exists

for the U.S. and its Allies to effect dramatic improvements in C3 systems. This program will exploit emerging technology through collaboration of U.S. and Allied engineers and scientists to determine how to build advanced distributed warfare simulation capabilities. The long range goal is to attain greatly improved C3 interoperability and warfare capabilities of the NATO forces.

This program will develop AI-based simulation technology and explore advanced distributed processing suitable for use in advanced wargaming and planning applications. To demonstrate the technology, a prototype of a distributed wargaming system that spans multiple distributed sites will be developed. The first step will be to analyze and evaluate candidate system hardware and software architectures for distributed AI-based simulation systems. Then simulation systems will be developed to support distributed wargaming and planning applications. Advanced modeling techniques to support multiple levels of granularity and abstraction of war activities will be developed. The program will also provide for integration of sophisticated user interface facilities that can input and output information in the form of natural language and graphic representations. Results of other DARPA research programs in secure packet-switched communications, distributed processing, distributed data bases, and expert systems, etc., will also be adapted to the wargaming and planning prototypes.

4. SUMMARY

In summary, the Information Science and Technology Office of DARPA is pursuing a multifaceted research program in advanced networking, distributed systems, and systems interoperability. This program incorporates a mix of base technology research and testbed programs designed to develop technologies to support future C3 systems. This research is characterized by its pursuit of new generation technologies. DARPA technology research is directed at broad-based DoD needs without specific military mission constraints. This allows DARPA to focus on high-risk technology research and on long-term operational requirements of current, future, and emerging military doctrine.